As it indicates, this is an interim report. It may be revised and republished prior to the final report.

As this report explains, this study involves many important land Intelligent Transportation Systems ("ITS") uses of C-HALO. It does not attempt to assess all ITS applica-tions, or applications in other sectors such as agriculture, mining, civil engineering and constru-ction; maritime, rail and aircraft ITS; digital map creation and maintenance, and other sectors.

Other materials Sky-Tel has provide in its Scribd C-HALO folder, including the Austrialian study on the benefits of nationwide C-HALO indicate that the total benefits of nationwide C-HALO in the US will be a substantial multiple of those projected in this focused UC Berkeley study.

In large part, the same C-HALO wireless-systems insfrastructure that can provide C-HALO for land ITS can also provide it to these other sectors.

As other papers in Sky-Tel's Scribd C-HALO col-lection suggest, nation-wide C-HALO may become one of the fundamental nationwide infrastructures in financial and quality-of-life benefits, after transportation, energy, telecommuni-cations and a few others. Thus far, it also appears likely to be well justified in terms of benefits to cost even if used only for the land ITS services involved in this study to date.]

INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

C-HALO Cost Benefit Study: Interim Report – August 2010

Adam Goodliss

Christian Manasseh

Adib Kanafani

Kannan Ramchandran

Raja Sengupta

Research Report
UCB-ITS-WP-2010-1

ITSBerkeley

August 2010

Table of Contents

Figures

Tables

Acknowledgment

Introduction

This study aims to develop a cost-benefit analysis for a Cooperative High-Accuracy-LOcation -- or "C-HALO"-- infrastructure for nationwide smart transportation, energy, environment and other critical services. "Cooperative" refers to cooperation among infrastructure elements such as satellites or terrestrial base stations and mobile elements such as vehicles or smartphones to realize the most effective and efficient high accuracy location services. To raise the quality of location information, we seek to comprehensively leverage current infrastructure including the current GPS constellation, Galileo, N-RTK, the computer, wireless, and IP networks, and the use of vehicles as excellent wireless platforms. The nations' demand for more "green" infrastructure and way of life offers new opportunity to transform infrastructure including that providing accurate positioning.

This report describes work in progress. Work has been undertaken on both benefits and costs. There are as yet no conclusive findings. The benefit evaluation work to date is focused on the safety and efficiency of road travel though location services have accelerated many sectors of the economy such as agriculture, aviation, mining, and defense, to name a few. Our cost work is focused on assessing the cost of augmenting the current infrastructure to deliver HALO and realize the safety and efficiency benefits. In addition to these two areas of work, the team has also undertaken a survey of the relevant cost-benefit literature. The survey has aimed to be comprehensive. Therefore the team welcomes information revealing work we might have missed. The following three areas of work are discussed in this interim report.

Benefit work: Location information impacts road travel by enabling new kinds of information services. To assess benefits we first identify new information services sought by society and enabled by a C-HALO capability. We then attempt to quantify the benefits of the services. Examples of such services include smart systems to manage infrastructure elements such as traffic signal corridors and applications for collision warning or traveler information resident on vehicles or an emerging generation of mobile personal computing devices such as smartphones or PDA's. A large group of such services have been identified by the different administrations of the USDOT over the past twenty years, advanced by the academic community and the ITS industry, and comprehensively managed at the policy level by the ITSJPO (Intelligent Transportation Systems Joint Program Office).

A subset of these services work only when the location information is good enough to know the lanes of travel of vehicles, i.e. positioning to a precision of 1 meter or less. We assume most such services require HALO. Accordingly the benefits of such a service, as evaluated in this study or the literature, are assigned to C-HALO. The analyses in section 4 show the benefits of C-HALO to road travel should lie between 40 and 70 billion dollars. This range does not include benefits flowing from services sufficiently enabled by a Low Accuracy LOcation (LALO) capability, even though a C-HALO infrastructure could be expected to support all LALO services.

Cost work: On the cost side we seek to quantify the new infrastructure investment required to realize a HALO capability. This means identifying the part of the United States in which C-HALO would deliver benefits and then identifying the sub-parts in which new infrastructure investment might be required to

deliver HALO. We term this sub-part in which HALO is valuable but not available without new investment, the "dark area". It is our hope that the dark area will be small meaning that for a moderate investment in new infrastructure a HALO capability can be ubiquitous enough to be relied on by people enabling new HALO reliant services. Ubiquity might be quantified by a GPS type national guarantee for HALO. The DoD assures the location based services industry that 97% of the time the GPS constellation will enable a receiver to know its position to a precision of 5 meters (1). The goal of the augmenting HALO investment might be to deliver a similar nationwide guarantee for high accuracy.

Thus our survey of the literature includes the impact of all GPS augmenting services we have been able to learn about such as Galileo, RTK, N-RTK, INS, etc. In parallel, we are developing a GIS model to estimate the fraction of roads currently lacking HALO. Though the national guarantee is 5 meters, in some areas covered by many satellites the GPS constellation does better. Section 5 presents data collected by us in the city of San Francisco showing dark areas. The roads marked red in Figure 4 are dark area with high confidence. Such small samples of data are being collected to calibrate the GIS model we will use for nationwide dark area estimates. Section 5 also describes the methodology for the GIS model.

Literature Summary: Finally section 3 is the current summary of the literature. It aims to include the relevant benefit assessment literature and the relevant literature on GPS and GPS augmenting infrastructure determining the cost of realizing HALO. The summary includes current and projected wide-area government positioning systems (primarily GPS and other GNSS and their current and projected augmentations) in order to identify their geographic coverage, accuracy and reliability across the nation. The cost assessment will utilize this summary to assess the gap between these current and projected systems, as compared to the increased coverage, accuracy and reliability requirements of C-HALO in its several contemplated phases. Knowing the size of this gap nationwide, we will be able to perform a cost analysis, estimating and comparing the benefits to the nation reaped by these increases, to the costs involved in achieving the increases using new, mostly terrestrial, positioning technologies becoming available in the market, and others that appear feasible.

Next Steps: The current work leaves gaps in the area of road travel itself and does not address other economic activities potentially impacted by HALO. In the area of road travel, HALO is an essential requirement for the Automated Highway prototype mandated by Congress in 1990 and delivered by NAHSC in 1997. This has potentially enormous emissions, safety, and productivity benefits. Other areas of the economy we are interested in addressing include the air and marine transportation systems, ports, and the unfolding growth of the smart energy infrastructure. Immediate next steps include the model development and dark area estimation work for cost assessment.

Motivation

The global positioning system (GPS) has been developed and deployed by the US government. Other GNSS are becoming upgraded (GLONASS) and established (Galileo, etc.) Extending the coverage, accuracy and reliability of GPS (GPS herein meaning all available GNSS) has been for years the objective of much private sector research and deployment efforts. For example, technologies such as DGPS, GPS-WAAS, GPS+INS, GPS-RTK, and network RTK(2,3) have been developed in recent years and are partially deployed. Limited-coverage pseudolite-based systems are also available, wide-area multi-lateration systems (4) are being substantially deployed around airports for aircraft and ground vehicle tracking. However, to this day no system has been proven to be able to ubiquitously provide accurate and reliable wide-area positioning information approaching what is needed for C-HALO. In most cases, such as with GPS-RTK, the cost of the positioning system in their limited uses (such as high-end agriculture and surveying) has been a barrier to wider-scale deployment. Moreover, these technologies rely on GPS, and only work well in areas where GPS reception is not weak or compromised by substantial radio multipath. In areas such as urban canyons and forested streets, or even in traffic with higher adjacent vehicles passing by, these systems will not function well. Certain new pseudolite-based solutions which can cover these dark areas are limited in range and are "not yet ready for prime time." Inertial navigation systems (INS) in vehicles can extend GPS coverage beyond areas of accuracy but not for substantial distances before loss of required accuracy. Wide-area multi-lateration systems being increasingly deployed around airports (as noted above) are cost-effective and sufficiently accurate for their purposes, but without modifications and far more extensive use of base stations, will not meet C-HALO requirements.

Recent and projected further advances in cooperative mobile communications, software defined radio (5), smart antenna systems (6), and other techniques, along with use of vehicles as excellent mobile communication platforms (7), may provide for advancements in positioning techniques and integrated systems.

Combinations of these will be needed for C-HALO, and phases seem needed for affordable, practical implementation, starting with higher value applications in geographic areas that can be affordably covered with sufficient accuracy and reliability, to eventual nationwide coverage, higher performance, higher volumes and lower per-unit cost, and an increasing range of applications extending to the mass market.

In addition to technological difficulties, deployment of C-HALO on the scale planned requires significant government support and funding. This has discouraged the private sector from aggressively attempting to resolve the technological issues. Overcoming the current technological hurdles and enabling C-HALO; therefore, warrants government and private foundation support of research and development initiatives.

This study aims at providing a tool which will enable government and private funding agencies to assess the benefits of investing in a new breed of positioning technologies and wide-scale deployments to meet the goals first noted above. It will shed light on the range of costs of the most promising technologies and their integration and phases of deployments in a nationwide C-HALO infrastructure.

The market analysis and literature review in section 3 indicates a lack of coverage of the benefits of C-HALO technology to the Transportation domain in general and ITS in particular. From the literature presented, efforts exist that attempt to quantitatively estimate the costs and benefits of high accuracy location data. These efforts are mostly market wide, or specific to an individual industry that is not transportation. In addition, plenty of literature exists to understand the costs and benefits of implementing certain ITS applications like curve speed warnings (8), or intelligent signal control systems (9). This later effort usually addresses the particular application under study and does not analyze the monetary benefits to the market; their results are presented in number of accidents reduced or total vehicle miles saved by the deployment of the application.

This lack of coverage of the transportation industry motivates us to tackle the job of estimating the economic benefits that could be reaped from a C-HALO nationwide deployment to the ITS sector of the transportation domain. It is the objective of this analysis to develop an exhaustive list of ITS applications that require high accuracy location data to realize the costs of implementation and the expected economic benefits that accompany each application.

Literature Summary

The first step in conducting a cost benefit analysis for a nationwide deployment of a new technology is to identify the domains which will get affected by this technology. As part of this effort, we review existing market analysis reports and cost benefit studies done by other on various sectors of the economy and in various parts of the globe. We present in this section our findings.

Market Analysis

Rob Lorimer of Position One Consulting performed a three year projection on the GNSS global market in his report titled: GNSS Market Research and Analysis September 2008 (10). Lorimer breaks down the GNSS market into four categories: Infrastructure, Receivers, Goods, and Services.

Infrastructure is typically broken down into three segments: ground, space, and augmentation. These three categories refer to the types of infrastructure necessary to provide high accuracy location data.

Receivers are the hardware that can receive and analyze the signals from the infrastructure system. These products are typically offered as OEM products to wholesalers, vertically integrated in other companies, or in exclusive contracts with other retailers.

Goods are typically bifurcated into machine goods and non-machine goods. This distinction is based off location goods for surveying (non-machine) and tractors (machine) for instance.

Services refer to either distribution or augmentation. Distribution services would be similar to what are provided to end users of personal navigation devices, while augmentation services are unseen to the end user, typically increasing the accuracy of the location data.

Value is typically generated through a number of channels, below is a thorough, but not exhaustive list of areas in the supply chain where value is created:

- Creating Augmentation Infrastructure
- Design and Manufacturing of Receiver Boards
- Product Development
    - Hardware
    - Software
- Distribution Channels
- Augmentation Services
- End User
    - Productivity gains

Currently, there are many industries beginning to benefit from the availability of high accuracy location data. Based on this report and analysis, a table of companies has been populated, along with which industry(ies) each company is involved in. This is completed without characterizing each company as a manufacturer, services provider, or some other level or combination of levels in the supply chain.

From Table 1, one can see that three of the most ubiquitous companies in the GNSS market are Leica Geosystems, Trimble, and TopCon/Sokkia. Omnistar is also relevant in many industries, but they are mainly focused on precision augmentation services, while the other three are more vertically integrated, and typically incorporate numerous levels of the value chain.

Table 1 Market Presence (X-Major; O-Minor)

	Aero.	Agri.	AV	Constr.	Def.	Mari.	Mine	Survey
Automated Positioning Systems							X	
Atair Aerospace					X			
Axio-Net GmbH	O	O		O		O		O
Biscarosse BV					X			
C&C Technologies						X		
Credent Technologies	X							
Crossbow Technology	O	O		O	O	O	O	O
DataGrid Inc.	O	O		O		O	O	X
Fugro/Omnistar	X	O	O	X		X	X	X
GeoKosmos	X							
GPS Ag		X						
Grumman			X		X			
Hemisphere GPS		X				O	O	O
Honeywell					X			
Javad GNSS				X				X
John Deere/Navcom Technology	X			O				
Leica Geosystems/ Novatel/Hexagon	O	X		X			O	X
Locata Corporation		O		X			X	
Magellan								X
MMIST Inc.					X			
NavSys Corportation	X	O	X	O			O	
Novariant	O	X		O	O		X	
New Zealand Aerial Mapping	X							
Septentrio BV	X					X		
Stara Technologies, Inc.					X			
Subsea 7/Veripos						X	X	X
Suzhou FOIF				X				X
TopCon/Sokkia	O	X		X		O	X	X
Trimble	O	X	O	X	O	X	X	X

Based on interviews with the CEO's of the companies listed above (10) provides market value projections for the particular industries for the period ending in 2011. We present below the major findings of this report.

- Aerospace
  - Market size was $7B in 2008 and is expected to grow to $10B in 2012
  - Leica is heavily active in this industry
  - Others like Credent Technologies, GeoKosmos, and NZAM are also active
  - Honeywell's SmartPath landing system
- Agriculture
  - Market it estimated at $4T by 2010
    - $90B in equipment
  - Biggest Players are John Deere, Trimble, Hemisphere GPS (New product launch in early 2010), GPS Ag (Australia) and Novariant
  - Available factory fitted or aftermarket
- Autonomous Vehicles
  - DARPA Challenge
    - Biggest Driver is still the Department of Defense
    - GPS assistance from Omnistar, Trimble, Grumman, & Septentrio
    - Some teams leverage LIDAR data
- Construction
  - Market is estimated at $4T
  - Biggest players are Trimble (Catepillar), Topcon (Komatsu), and Leica Geosystems
- Defense
  - Raytheon ($233M) is developing a GPS landing system for Navy aircraft
  - GPS Guided Airdrops
    - Atair Aerospace
    - Biscarosse, MMIST Inc., Stara Technologies, Inc. et al.
- Maritime/Container Handling
  - Shore based systems dominated by Trimble and Leica Geosystem
  - Off-shore bases systems dominated by Omnistar, Veripos, and C&CT
  - Container technology mostly OEM products from Novatel and Navcom
- Mining
  - Biggest Players are Trimble (Caterpillar) and Leica Geosystems
  - Also in the market are APS and Novariant
- Surveying/Deformation Monitoring
  - Trimble (NA), TopCon/Sokkia (Japan), and Leica Geosystems (Europe)
    - Control 80% of market revenue in providing GNSS goods and services
    - Competition may be forthcoming

Benefit Analysis of GNSS

As part of our analysis, a due diligence was done on the literature involving GNSS and CBAs. Below we list the related research and publications with a brief discussion of their content.

A study was conducted by the Allen Group (11), which attempts to quantify and estimate the economic benefits of HALO type technology in three specific industries: Agriculture, Mining, and Construction. For reference the report was also written about the Australian economy and respective industries. Through their analysis they determine the benefits to be between $100 and $200 billion.

Although not directly analyzing ITS applications, this report shows that people are interested in understanding the economic effects of HALO technology, and it is likely that being able to understand that effect with regards to ITS will be increasingly valuable as well.

In addition, a key piece of our analysis is leveraged from this report. The adoption rate for the C-HALO technology is represented by this studies' industry-wide national rollout adoption scenario. The study does go on to adjust the industry wide scenario to the specific industries in their report, and this is something to consider going forward with ITS applications.

A socio-economic benefit study was commissioned by US Department of Commerce (12) to determine where there is value added by the CORS and GRAV-D systems. The study suggests the surveying and mapping industry will be the most significantly impacted, but go on to list other possible industries like construction, agriculture, environmental science, and transportation.

When they begin to assess benefits the study utilizes the productivity methodology, which is typical and similar to the methodology used in our study and many others contained in the literature review. One slight difference to our methodology is that their time horizon is 15 years while ours is a bit longer.

Ultimately, they estimate ~$34 billion in benefits with $7 billion attributable to CORS, $4.8 billion attributable to GRAV-D, and the remaining $22 billion to NSRS. In these figures, they also include benefits due to avoided costs. A lot of value is also realized in elevation accuracy and not necessary in the x-y plane.

Leveson Consulting, who penned the article, Benefits of the New GPS Civilian Signal – The L2C Study (13), tries to estimate the civilian benefits of the new L2C technology. In their benefits calculations, they do not use the aviation or defense industry, but also do not shed much light on to how they chose applications or the actual calculation of benefits. Most of the information was from other studies, expert opinion, or other case histories. They do, however, use the same economic productivity methodology as most do. Ultimately, they determine an overall benefit to civilians of ~$5.8 billion which turns out to be between $8K and $16K per user.

Alcantarilla, et al. analyze the benefits of a multi-constellation system, versus a stand-alone GNSS system, and ultimately a SBAS approach (14). A piece that may be of importance to us when discussing the costs is the distribution of the number of satellites in view. They conduct a simulation of an urban environment and contend that with GPS & Galileo 65% could view more than 3 satellites, while 20% could view 3, and 15% viewed less than 3. They then go on to qualitatively discuss the principal pieces of a future GPS system along with the envisioned benefits of multi-constellation GNSS SBAS augmentations.

Swann, et al. discuss the benefits (qualitative, not quantitative) of location-based services, as well as discussing architectural issues and also addressing the market aspects as well (15). They discuss in depth the benefit of reliability by using a combined GPS/Galileo signal where availability rated at 99.7% in their Stuttgart analysis. In addition, they estimate the GNSS service provision market to be 135 billion Euros by 2015 with a significant portion of that residing in the transportation industry.

Vollath, et al. aimed to look at how NRTK and the third frequency to be offered by Galileo will interact (16). Throughout the study it is mentioned that the third frequency will be extremely valuable in that it will allow higher horizontal accuracy and increase distances between base stations among other things. NRTK, however, will still prove to more accurate in the vertical direction. Ultimately, they do not assess the benefits in a monetary fashion, but only in reliability. They conclude that NRTK will not be replaced by the new third frequency, but they will complement each other.

Arthur, et al. delve deeper into the impacts of Galileo by going beyond cost benefit analyses and conducting input-output models (17). They even go as far to suggest that these 'market externality' impacts could be twice as large as the direct impacts. They suggest how to take a CBA to the next level by including innovation effects (through supply-push or demand-pull forces), or market and social externalities. These types of analyses could be worthwhile down the road to more fully understand these effects with relation to our study.

Brennan, et al. wrote National PNT Architecture: Interim Results to facilitate the decision making process on a national PNT architecture for the United States by 2025(18). It does not discuss heavily any costs or benefits in quantitative terms. It does however evaluate many different technological options to achieve their stated goals. Ultimately, they want to put together a transition plan from an "as is" architecture to a "should be" architecture. Unfortunately, this is not directly related to our CBA.

Benefit Assessment

The initial approach was aimed at determining, on a conservative basis, the benefits of a suite of ITS applications that require high accuracy location data. The ITS applications analyzed were those listed by the FHWA (19). See Appendix A – for a comprehensive list of the applications and their description. Subsequent to the literature review process 44 applications were collected. After the literature review process, a rough analysis of location accuracy requirements was completed. This filtered down the application list to about 8 groups of applications based on their requirements of location accuracy. If the applications required 1m or less accuracy those applications and subsequent benefits would be analyzed. Please see Appendix A – Process of Selecting ITS Application that Stand to Benefit from C-HALO for estimated accuracy requirement from the National ITS Architecture. These applications fell into at least one of three categories: Safety, Mobility, or Sustainability.

Once the list was finalized, each application was explored independently to determine the efficacy rate, and the monetary benefit from reducing accidents (and in turn injuries and fatalities), VMT, travel times, emissions, and the like depending on the application. This type of methodology is similar to those used in other CBA's completed by the USDOT and other international governmental agencies.

The final list of applications can be seen in the Table 2 below:

Table 2 ITS Applications that Benefit from C-HALO Deployment

ITS Applications	Type	Included in Benefit Analysis
Curve Speed Warning	**Safety**	**Y**
Forward Collision/Braking Warning	**Safety**	**Y**
Emergency Electronic Brake Lights		
Cooperative Forward Collision Warning		
Merge/Lane Change Applications	**Safety**	**Y**
Highway Merge Assistant		
Lane Change Warning		
Blind Spot Warning		
Blind Merge Warning		
Left Turn Assistant	**Safety**	**Y**
Stop Sign Movement Assistant	**Safety**	**Y**
Highway/Rail Collision Warning	**Safety**	**Y**
Intersection Collision Warning	**Safety**	**Y**
Corridor Management	**Mobility**	**Y**
Intelligent Traffic Flow Control		
Free-Flow Tolling		

Currently, there are only two mobility applications included in this estimate, but this is likely to expand going forward. In addition, we have yet to quantify any sustainability benefits, but as mentioned above, a literature review of the ITS, safety, mobility, and sustainability literature is in progress. The quantification process will be part of the next level of analysis.

Assumptions

Some overall assumption had to be made to estimate the benefits. Overall assumption cover predictions we make about the national economy into the next 20 years, and general assumptions on how the new technology would be adopted by the ITS sector. We later on make application based assumptions to estimate the particular use and efficacy of each application.

Technology Adoption Rate – The shape of this curve determines how quickly the fleet will adopt new technology, in this case C-HALO. The s-curve used in this analysis was leveraged from a report, by the Allen Group (11), which analyzes the benefits of high accuracy location data in non-ITS industries. The general shape of the curve is in Figure 1.
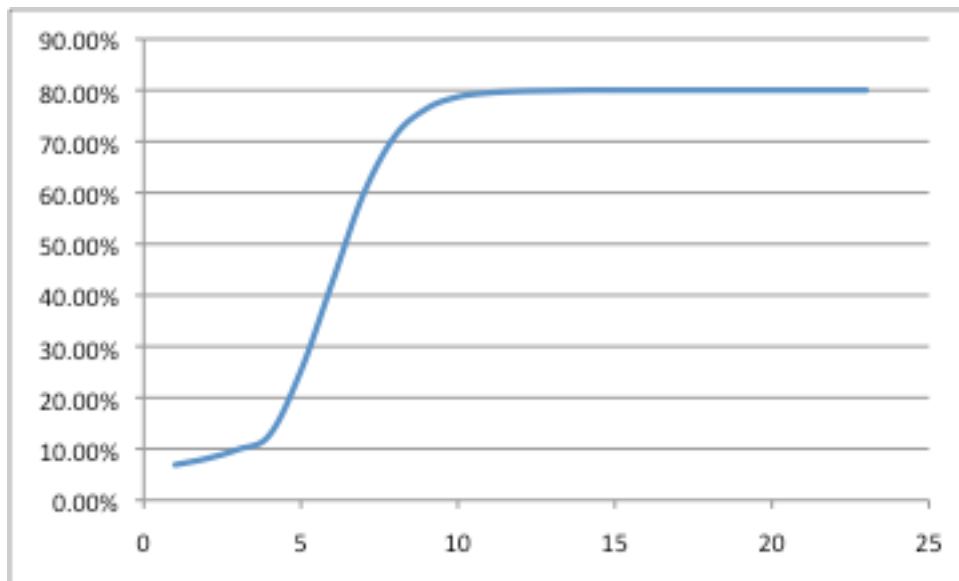
Figure 1 Technology adoption curve

This curve was applied over a project horizon of 22 years, 2008 – 2030. In calculating benefits, this adoption rate was typically used to determine the correct portion of benefits accumulated in a given year.

Discount Rate – This rate is used to discount future cash values to current day terms by taking into account inflation and a risk free rate of return, the higher the rate the more significant the discount to future cash values. For this analysis, a discount rate of 5 percent is used, and was leveraged from the Office of Budget and Management (20). They also suggest using a range from 3 to 7 percent. These ranges will ultimately be included in our sensitivity analysis.

Value of Time – The value of time was used in quantifying reductions in delay into monetary benefits. Again, the Volpe study quotes two figures, one for local travel, $11.20, and the other for intercity travel $15.60. These figures are from guidance from the office of the Secretary of Transportation (21). In our analysis, we took both figures and averaged them since in our data there was no way to bifurcate between intercity and local travel. The resulting figure was $13.40.

Delay Growth – The delay growth was calculated using figures from the Traffic Congestion and Reliability Report prepared by Cambridge Systematics for the FHWA in 2005 (22). Using twenty-year historical data (hours of delay per traveler) and trend analysis a growth rate of 6.5 percent was calculated.

Sources of Data

Accident Data – For the Safety applications, all accident data was culled from the FARS database (23) which only included injuries/fatalities from fatal accidents. This database was then queried to ensure the appropriate accidents are being accounted for with regards to each individual application. Please see Appendix B for the querying methodology for each application class.

Accident Growth Rate – The accident growth rate was used to project accident counts for years 2009 – 2030. The Volpe VII report projects accident rates based on VMT estimates and increased safety measures. These yearly accident rates were used to calculate the compound annual growth rate over the project horizon (21) This rate was calculated to be -0.2 percent.

Fatality Worth – This value is used in determining the benefit of reducing the count of fatal accidents. The Office of Management and Budgets put forth a memorandum in 2008 that suggests to the DOT that $5.8 million be used for the value of a life. It also suggests using a range of $3.2 million to $8.4 million (24).

Injury Worth – These values are based on percentages of the fatality worth. Again there is a standard, and that is the Maximum Abbreviated Injury Scale. Typically there are 5 injury levels not counting a fatality (24). In the FARS database only three levels of injuries are reported not counting fatalities. Therefore averages were taken first and second level and the third and fourth levels to determine the three percentages used in this analysis. The following percentages are used Table 3.

Table 3 Injury Worth Percentages

Injury Worth (% of Fatality Worth)	
Incapacitating	47.50%
Non-Incapacitating	5.80%
Possible/Light Injury	0.90%

Benefits from ITS Applications

Safety Applications

As part of the safety analysis, seven applications were analyzed: Curve Speed Warning, Forward Collision Warning, Merge/Lane Change Warning, Left Turn Assistants, Stop Sign Movement Assistant, Highway/Rail Collision Warning, and Intersection Collision Warning. All of these applications are focused on reducing accidents, and in turn fatalities and other injuries. In further analyses these applications will be looked at from possible sustainability and mobility perspectives as well.

Curve Speed Warning

Curve speed warnings would aid drivers in negotiating curves at appropriate speeds. This is aimed at reducing single and multi-vehicle accidents in curves due to unsafe speeds.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 1280 accidents, 1360 fatalities, and ~600 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective curve speed warnings could be. The three reports and results are summarized briefly below:

- Field Evaluation of the Myrtle Creek Advanced Curve Warning System (Oregon DOT 2006) – Empirical analysis of I-5 implementation near Myrtle Beach, over 75 percent of people reduced speeds entering the curves with dynamic message signage. The FHWA report (21) uses this value as a measure of efficacy of the curve speed warning applications when assessing the benefits of wireless communication to ITS.
- Rural ITS Toolbox (FHWA 2001) – Empirical study for trucks in Colorado. Speeds were reduced by 25 percent.
- An Evaluation of Dynamic Curve Warning Systems in the Sacramento River Canyon: Final Report (CA DOT 2000) - Empirical analysis of five locations on I-5 in California, over 70 percent of people reduced speeds entering the curves with dynamic message signage.

Using these sources as references, we chose to use 40% accident reduction as a mid-level efficacy rate. A low level would be 20% while a high efficacy level would be 70%. For a matrix of the efficacy rates please see Appendix C.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$13 Billion were estimated.

Forward Collision Warning

Forward collision warnings alert a driver when a forward vehicle brakes hard (deceleration is above a predetermined threshold). This is very similar to Cooperative Forward Collision Warning which is used to preemptively avoid rear-end collisions with vehicles in front of the subject vehicle.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 482 accidents, 300 fatalities, and ~250 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective forward collision warnings could be. The three reports and results are summarized briefly below:

- Evaluation of an Automotive Rear-End Collision Avoidance System (Volpe 2006) – A study that analyzed data from a field operation test and the results suggest that 10% of all rear-end collisions could be reduced.
- Integrated Vehicle Based Safety Systems: A Major ITS Initiative (FHWA 2005) – A study on IV systems that suggests these types of applications could reduce rear end, run off road, or lane change collisions by 48%.
- The Evaluation of Impact on Traffic Safety of Anti-Collision Assist Applications (Sala, Gianguido & Lorenzo Mussone, 1999) – A simulation study that suggests between 10 and 60% accident reduction could be attainable depending on the adoption rate of the technology. This is very interesting and one of the only studies that addresses changes in effectiveness due to technology adoption.

Using these sources as references, we chose to use 25% accident reduction as a mid-level efficacy rate. A low level would be 10% while a high efficacy level would be 50%.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$1.5 Billion were estimated.

Merge/Lane Change Warning

These warnings would alert vehicles on highway on-ramps if another vehicle is occupying its merging space (or in its blind spot). This is similar to Blind Merge Warning where warnings are used for vehicles attempting to merge with limited sight distance, and another vehicle is predicted to occupy the merging space. In addition, this system could warn the subject driver if a lane change is likely to cause a collision, triggered by turn signal activation.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 439 accidents, 343 fatalities, and ~220 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective merge or lane change warnings could be. The four reports and results are summarized briefly below:

- Integrated Vehicle Based Safety Systems: A Major ITS Initiative (FHWA 2005) – A study on IV systems that suggests these types of applications could reduce rear end, run off road, or lane change collisions by 48%.
- Freightliner to Offer Collision Warning on New Truck Line (Inside ITS 1995) – Empirical study of Transport Besner Trucking Co, which reduced its at-fault accidents by 34%.
- Dutch Field Operational Test Experience with "The Assisted Driver" (Alkim, Boostma, and Hoogendoorn 2007) – Empirical study of 20 vehicles in the Netherleands equipped with warning systems which were driven for five months. It found that unintentional lane changes were reduced by 35% on arterials, while it was reduced by 30% on highways.
- Run-Off Road Collision Avoidance Using IVHS Countermeasures: Final Report (NHTSA, 1999) – A simulation study that looked at lane departure warnings. Suggests passenger vehicle lane departures would decrease by 10%, while heavy trucks would decrease by 30%.

Using these sources as references, we chose to use 35% accident reduction as a mid-level efficacy rate. A low level would be 15% while a high efficacy level would be 60%.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$2.6 Billion were estimated.

Intersection Collision Warning
Intersection Collision Warning applications provide warnings to drivers that a collision is likely at the upcoming intersection either due to their own speed or inattention, or that of another driver.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 294 accidents, 204 fatalities, and ~150 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, several reports were found discussing how effective intersection collision warnings could be. The two reports and results are summarized briefly below:

- Field & Driving Simulator Validations of System for Warning Potential Victims of Red-Light Violators (Inman, Vaughan TRB 2006) – A Field and Simulation study that tested participants in a driving simulator and on a closed track. In the simulator, 90% stopped or avoided the collision, while on the track, 64% stopped or avoided the collision.
- Intersection Collision Avoidance Study (FHWA Office of Safety 2003) – An in depth analysis of literature and operational concepts of specific ICAS systems, and they state that 100% reduction in accidents is not unrealistic, however a more conservative estimate would be a 50% reduction in accidents.

Using these sources as references, we chose to use 50% accident reduction as a mid-level efficacy rate. A low level would be 25% while a high efficacy level would be 75%.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$2.5 Billion were estimated.

Left Turn Assistant

Left Turn Assistants provide drivers information about oncoming traffic when trying to take a left-hand turn at an unprotected intersection.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 1170 accidents, 605 fatalities, and ~600 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Since the application is very similar to that of intersection collision warnings, the literature used to determine an efficacy rate for that application were leveraged for this application as well.

Using these sources as references, we chose to use 50% accident reduction as a mid-level efficacy rate. A low level would be 25% while a high efficacy level would be 75%.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$7.7 Billion were estimated.

Stop Sign Movement Assistant

Stop Sign Movement Assistants alert vehicles about to cross an intersection, after stopping, of cross traffic.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 482 accidents, 300 fatalities, and ~250 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Since the application is very similar to that of intersection collision warnings, the literature used to determine an efficacy rate for that application were leveraged for this application as well.

Using these sources as references, we chose to use 50% accident reduction as a mid-level efficacy rate. A low level would be 25% while a high efficacy level would be 75%.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$1.3 Billion were estimated.

Highway/Rail Collision Warning
Highway/Rail Collision warnings provide alerts to reduce the likelihood of a collision between vehicles and trains on intersecting paths.

To quantify the benefits of such a system we aimed to determine the number of accidents that could be reduced, then by using the assumptions laid out in previous sections, calculate a monetary benefit for reducing accidents.

To begin this process, the FARS database was queried for specific accident data related to the application in question. For instance, all accidents that took place in curves, and were related to speed were included in this analysis.

In 2008, there were 18 accidents, 23 fatalities, and ~5 other injuries where this type of application may be applicable. To determine the benefit of this system an efficacy rate must be determined to see how much of a reduction from these figures can be expected.

Through another literature review, a report was found discussing how effective Highway/Rail Crossing Warnings could be. The report and results are summarized briefly below:

- Second Train Coming Warning Sign Demonstration Projects (TCRP Research Results Digest, 2002) – A demonstration study of two sites, one in Baltimore and the other in LA, where warnings were placed for approaching trains. 26% of drivers reduced the most risky behavior.

Using these sources as references, we chose to use 25% accident reduction as a mid-level efficacy rate. A low level would be 10% while a high efficacy level would be 50%.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B = (EffRate_j * Adopt_n * \sum (InuryCount_{i,n} * Injury\%_i * FatalityWorth)) / DiscountFactor_n$$

Where B is monetary benefits, n is the year, j is the application, and i is the injury level (fatal, serious, etc.).

Using this formula, preliminary benefits of ~$0.1 Billion were estimated.

Mobility Applications

As part of the mobility analysis, two applications were analyzed: Intelligent traffic flow control and free flow tolling. Both of these applications are focused on reducing delay. Both those applications require lane-level positioning accuracy to operate and therefore would benefit from a C-HALO nationwide deployment. In further analyses these applications will be looked at from a sustainability perspective as well.

Intelligent Traffic Flow Controls (ITFC)

ITFC uses real-time data to adjust signal phases to an optimal level. These applications could also include Green Light Optimal Speed Advisory, which would provide the subject vehicle with the optimal speed given signal phase timing at upcoming intersections.

To quantify the benefits of such a system two additional pieces of information were needed to complete the calculation. The first is to determine how much delay is currently realized at signalized intersections. This was done through a literature review, and Temporary Losses of Highway Capacity and Impacts on Performance (Phase 2), written by Oak Ridge National Laboratory for the Department of Energy, discusses sub-optimal signal timing specifically. Through surveying and significant quantitative modeling they determine that there is, as of 1999, ~295 million hours of delay at signalized intersections.

Lastly, the efficacy of these new systems needs to be estimated. Through another literature review, several reports were found discussing how much more optimal signal timing assisted in reducing delay. The three reports and results are summarized briefly below:

- Preliminary Evaluation Study of Adaptive Traffic Control System (LA DOT 2001) – Empirical study in LA with 375 intersections, reduced delay by ~21%
- Realizing Benefits of Adaptive Signal Control at an Isolated Intersection (Park and Change 2002) – A simulation study on a hypothetical intersection of two one-way streets. Reductions in delay were between 18-20%
- ITS Benefits: The Case for Traffic Signal Control Systems (Skabardonis 2001) – Empirical study of multiple California implemented systems, reductions of delay close to 25%.

Using these sources as references, we chose to use 15% delay reduction as a conservative efficacy rate.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B_n = (EffRate * Adopt_n * TotDel_n * TVoM)/DiscountFactor_n$$

Where B is monetary benefits, n is the year, and TVoM is the monetary value of time.

Using this formula, preliminary benefits of ~$10 Billion were estimated.

Free Flow Tolling

Toll collection without toll plazas reducing stop and go traffic surrounding current toll plazas, also beneficial, but not included in this analysis is the fact that in tolling situations, costs are actually saved by not having to build facilities. In this exercise we only look at reduced delay.

To calculate the delay reduced by free tolling systems, some metrics needed to be deciphered. Average delay at a toll facility, the total revenue of all tolling facilities, and the average toll for toll roads in the U.S is three metrics needed to calculate total delay due to toll facilities. Again, this was done through a literature review, and Temporary Losses of Highway Capacity and Impacts on Performance (Phase 2), written by Oak Ridge National Laboratory for the Department of Energy, discusses average toll delay. Through thorough quantitative analysis, they determine the average tolling delay to be 11.9 sec per vehicle.

With this figure, only the number of vehicles would be necessary to determine overall delay. To determine the number of vehicles using toll facilities, total tolling revenues and average toll were sought. In the Highway Statistics 2007 published by the FHWA, the total revenues of toll facilities was $7.7 billion, while in the Toll Facilities in the U.S. August 2009, the average toll is calculated to be $3.89 (25). Using these two figures, an annual vehicle count of ~2 billion was determined. This was grown on a year-to-year basis at a rate of 1.65% (26).

Lastly, the efficacy of these new systems needs to be estimated. Through another literature review, several reports were found discussing how much free tolling systems reducing delay. The two reports and results are summarized briefly below:

- Evaluation of Impacts from Deployment of an Open Road Tolling Concept for a Mainline Toll Plaza (Klodzinski 2007) – Twenty-month empirical study done around UCF which reduced delays by approximately 50 percent.
- Operational and Traffic Benefits of E-Zpass to the New Jersey Turnpike (NJ Turnpike Authority 2001) – EZ-pass empirical study that showed 85 percent reductions in delay.

Using these sources as references, we chose to use 70% delay reduction as a conservative efficacy rate.

With all of this data, a discounted yearly monetary benefit can be calculated. The equation would as follows:

$$B_n = (EffRate * Adopt_n * TotVeh_n * AvgDel * TVoM)/DiscountFactor_n$$

Where B is monetary benefits, n is the year, and TVoM is the monetary value of time.

Using this formula, preliminary benefits of ~$0.6 Billion were estimated.

Efficacy Literature Caveat

Almost all the current efficacy literature was culled from the RITA ITS Benefits database online. Due to this, some of the efficacy figures may be overstated. To confirm these figures we have begun some research of other institutions and groups that may have different points of view or methodologies that lead to different results.

To date, we have found documents from the GAO (27), RAND (28), and CBO (29) that do not challenge the assumptions made and published by the DOT with respect to the analyzed applications.

Summary of Benefits

After completing all these individual analyses, the sum of these benefits ranges from $40 billion to $70 billion. This range depends on whether one uses the mid-level safety application efficacy rates or the low-level efficacy rates. This translates into 0.3 to 0.5 percent of GDP. The safety benefits in the analysis dominate, making up almost 70 percent of the total benefits calculated. Another thing to understand going forward is that sustainability benefits still need to be calculated and addressed. These are believed to be significant and should increase this total figure further. In addition, the safety figures will also increase due to the fact that in this analysis the database was limited to fatal accidents whereas our ultimate analysis will be more exhaustive.

Cost Assessment

In order to estimate the cost of delivering C-HALO we need to estimate the existing accuracy of location services on the ground in order to assess the "gap" or "dark area". We think of the dark area as the US land area in which high accuracy location is not provided by the GPS constellation and its already well established augmentations, such as WAAS corrections for example. Emerging deployments of interest to us include N-RTK and the penetration of INS systems in vehicles. For example, we know from our prior work (30) that GPS augmented with INS can dead reckon to lane level precision for about 20 seconds if there are no sudden lane changes or turns at intersections. Data such as this in the literature as well as evaluations of current N-RTK deployments will be used to estimate the extent and cost of a new HALO infrastructure. (31,32)

Several reports exist on the causes of errors when measuring position on the ground using the GPS system(33). These reports address the theoretical values of the various types of errors. Table 4 below shows the possible values for the different causes of the errors attributing to locating objects on the ground using GPS.

Table 4 Sources of GPS Errors

Source	Effect (m)
Signal Arrival C/A	±3
Signal Arrival P(Y)	±0.3
Ionospheric effects	±5
Ephemeris errors	±2.5
Satellite clock errors	±2
Multipath distortion	±1
Tropospheric effects	±0.5
σ_R C/A	±6.7
σ_R P(Y)	±6.0

As part of this study, we set out to estimate the size of the "gap" by using empirical and data modeling techniques to arrive at a more accurate assessment of GPS accuracy on the ground. Our method for doing this relies on understanding the satellite coverage and the visibility of satellites from the Point-of-Interest (POI) on the ground. By taking a POI in an open space environment, the GPS receiver is capable of communicating with several satellites (6 or more) and as a result be able to locate the POI with good accuracy (1-3m). When comparing this POI with another POI in a dense urban setting with several high-rises, the number of satellites viewed drops significantly resulting in a lower accuracy of position detection (10m or more).

Our effort rests on modeling the relation between position accuracy and number of satellites-in-view by incorporating the PDOP values, the height of buildings near the POI, and the open-space area - as represented by street widths - into the model.

In order to build and validate the model, we will focus on the San Francisco Downtown area as defined in Figure 2
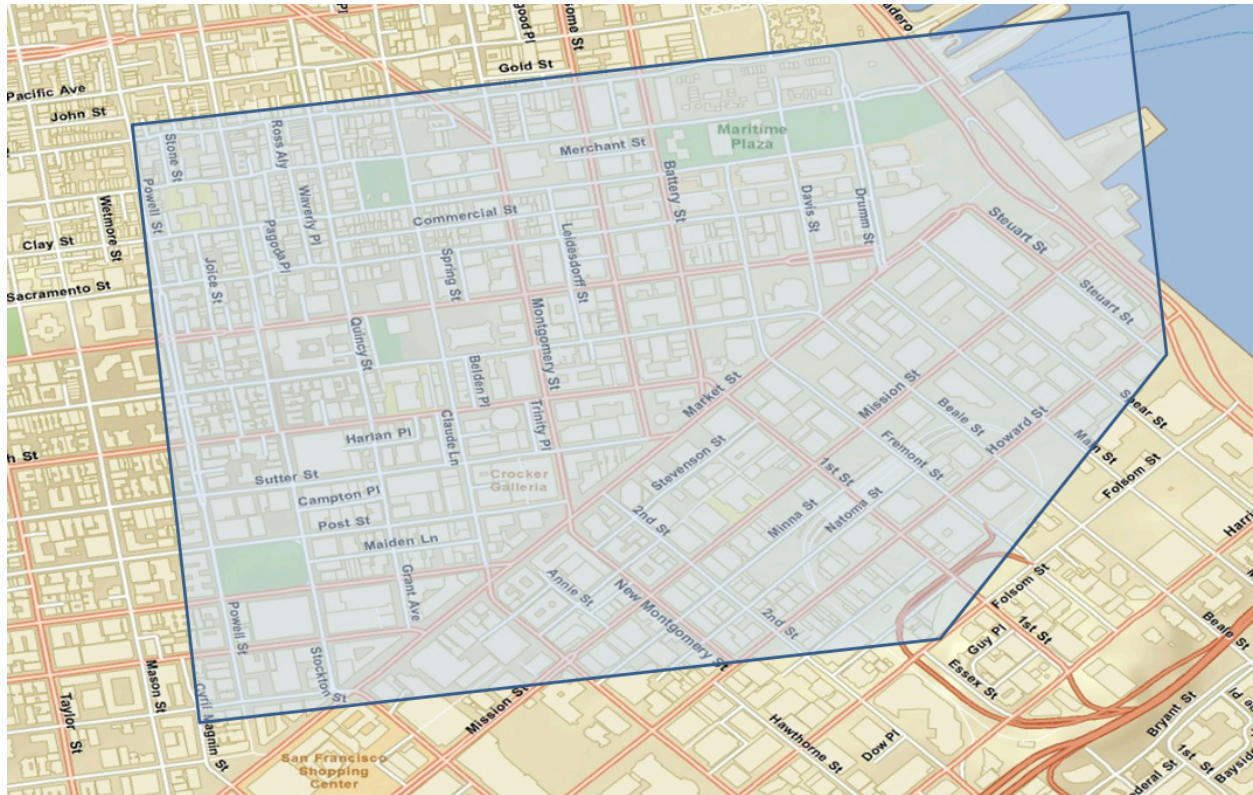
Figure 2 Shaded area represents study area

The area under study encompasses building of various heights providing us with a good range of satellite counts. Figure 3 shows the structures that exist in this area as of 2009.

Figure 3 3D rendering showing building coverage in study area

The model will be constructed using the ESRI GIS software ArcMap. Data for the model will include the following sources:

- Building heights as reported by the SFParcel GIS system controlled by the County of San Francisco
- Street width as measured using the ArcMap GIS software

The above two source will be treated as the "known" variables in the model. The "unknown" variable would be the satellite count. To build the model we would need to get the satellite count as measured on the ground in the proposed area. That could be done by driving around with a Smartphone equipped with a GPS sensor. A Smartphone application was developed on the Windows Mobile 6.5 operating system and deployed on two HTC phones. The HTC Diamond and the HTC Touch Pro 2. The GPS sensor in the Smartphone is capable of logging the following values of interest:

- GPS Longitude and Latitude
- Number of Satellites Visible
- Number of Satellites Connected
- Vertical Dilution of Position (VDOP)
- Horizontal Dilution of Position (HDOP)

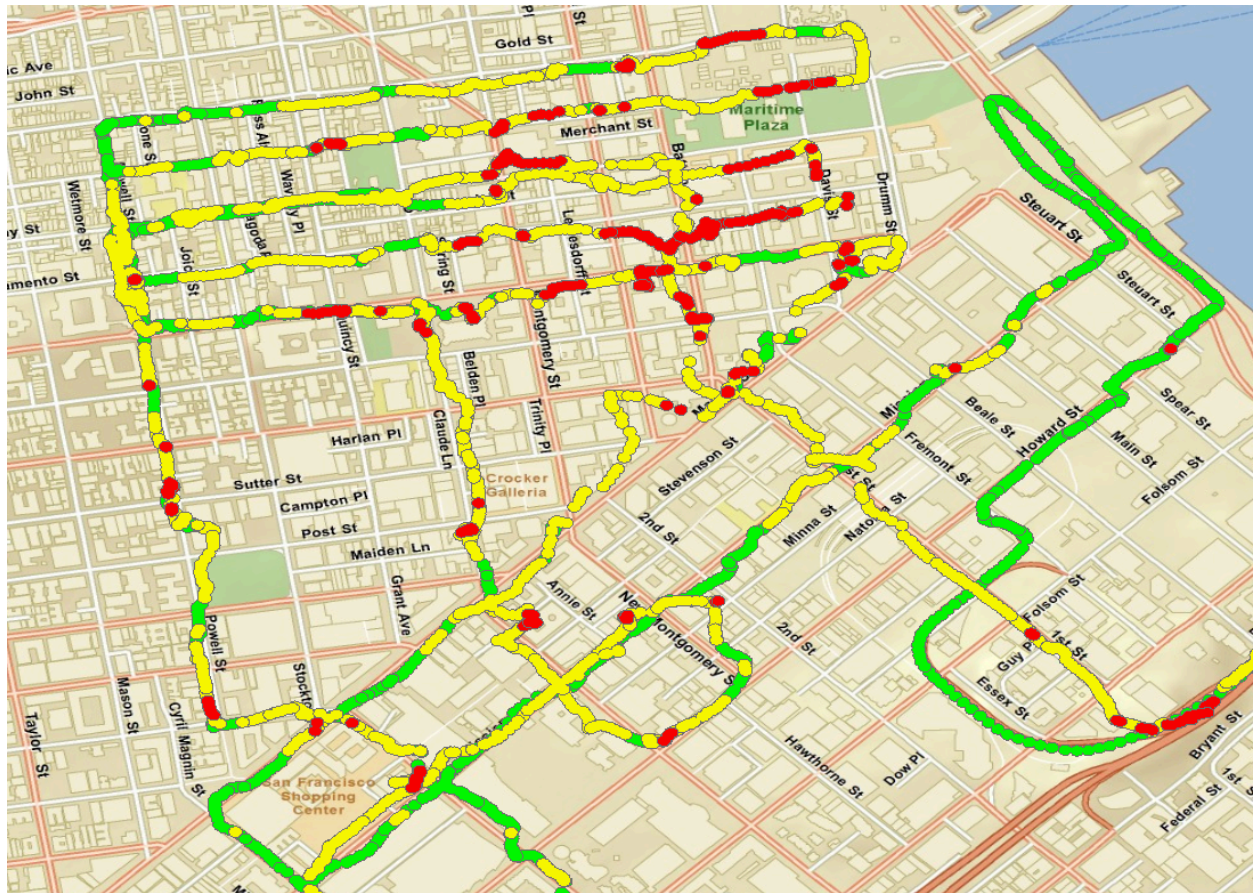The preliminary data collected is shown in Figure 4.

Figure 4 GPS data collection depicting satellite counts: 7 or more are shown in green, between 4 and 7 are shown in yellow, below 4 are shown in red

Once data collection is complete we will estimate the GIS Inverse Distance Weighting (IDW)(34) that governs the relation between satellite count with respect to building heights and street widths.

References

1. Department of Defense. Global Positioning System 2008: A Report to Congress. http://pnt.gov/public/docs/2008/biennial2008.pdf. 2008
2. Brain, Marshall and Harris, Tom. How GPS Works. How Stuff Works. http://electronics.howstuffworks.com/gadgets/travel/gps4.htm. Accessed August 23, 2010.
3. Wanninger, Lambert. Introduction to N-RTK. International Association of Geodesy. June 16 2008. http://www.wasoft.de/e/iagwg451/intro/introduction.html. Accessed August 23, 2010.
4. PRNewswire. Sensis Multilateration Systems Meeting the Demands of Continually Changing Airports. Airport Business. July 13, 2010http://www.airportbusiness.com/web/online/Top-News-Headlines/Sensis-Multilateration-Systems-Meeting-the-Demands-of-Continually-Changing-Airports/1$37952. Accessed August 23, 2010
5. Tuttlebee, Walter. Advances in Software Defined Radio. Annals of Telecommunications. Vol 57, No 5-6, p 314-337. http://www.springerlink.com/content/5784533018364762/. Accessed August 23, 2010.
6. Sun, Chen; Cheng, Jun; and Ohira, Takashi. Handbook for Advancements in Smart Antenna Technologies for Wireless Networks. IGI Global. July 2008. http://my.safaribooksonline.com/9781599049885. Accessed August 23, 2010
7. Hiraiwa, et al. Mobile Communication Platforms for ITS Services. Hitachi Review Vol 52, No 1. 2003
8. California Department of Transportation. An Evaluation of Dynamic Curve Warning Systems in the Sacramento River Canyon: Final Report. 2000
9. Skabardonis, Alex. ITS Benefits: The Case for Traffic Signal Control Systems. 2001.
10. Gakstatter, Eric and Lorimer, Robert. GNSS Market Research and Analysis. Position One Consulting Pty Ltd. September 2008.
11. Economic Benefits of High Resolution Positioning Services. The Allen Consulting Group Pty Ltd. November 2008.
12. Leveson, Irving. Socio-Economic Benefits Study: Scoping the Value of CORS and GRAV-D. Leveson Consulting. January 2009.
13. Levson, Irving. Benefits of the New GPS Civil Signal. Leveson Consulting. July/August 2006.
14. Alcantarilla, I., Porras, D., Tajdine, A., Zarraoa, N., Lévy, J.C., "The Benefits of Multi-constellation GNSS Augmentations," Proceedings of the 19th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2006), Fort Worth, TX, September 2006, pp. 930-938.
15. Swann, J., Chatre, E., Ludwig, D., "Galileo: Benefits for Location-Based Services," Proceedings of the 16th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS/GNSS 2003), Portland, OR, September 2003, pp. 1603-1612.
16. Vollath, Ulrich, Patra, Richard, Chen, Xiaoming, Landau, Herbert, Allison, Timo, "GALILEO/Modernized GPS: A New Challenge to Network RTK," Proceedings of the 17th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2004), Long Beach, CA, September 2004, pp. 2855-2863

17. Arthur, Daniel, Jenkins, Bryan, von Tunzelmann, G. Nick, Styles, Jon, "The Macroeconomic Impacts of Galileo," Proceedings of the 18th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2005), Long Beach, CA, September 2005, pp. 381-389.
18. Brennan, Shawn M., Van Dyke, Karen, "National PNT Architecture - Interim Results," Proceedings of the 63rd Annual Meeting of The Institute of Navigation, Cambridge, MA, April 2007, pp. 614-623.
19. The CAMP Vehicle Safety Communications Consortium. Identify Intelligent Vehicle Safety Applications Enabled by DSRC. March 2005.
20. Nussle, Jim. Memorandum for the Heads of Departments and Services. Office of Management and Budget. December 12, 2008.
21. Economic and Industry Analysis Division, John A. Volpe National Transportation Systems Center, United States Department of Transportation. Vehicle-Infrastructure Integration Initiative: Benefit-Cost Analysis Version 2.3. May 8, 2008.
22. Cambridge Systematics. Traffic Congestions and Reliability: Trends and Advanced Strategies for Congestion Mitigation. September 2005.
23. The Fatality Analysis Reporting System. http://www-fars.nhtsa.dot.gov/QueryTool/QuerySection/SelectYear.aspx. Accessed August 23, 2010.
24. Revised Departmental Guidance: Treatment of the Value of Preventing Fatalities and Injuries in Economic Analyses. Office of Management and Budget. 2008.
25. Toll Facilities in the United States. Office of Highway Policy Information. August 2009. http://www.fhwa.dot.gov/ohim/tollpage.htm. Accessed August 23, 2010
26. Traffic Volume Trends. Federal Highway Administration. http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm. March 2010 & March 2009. Accessed August 23, 2010.
27. Foresight Issues Challenge DOT's Efforts to Assess and Respond to New Technology-Based Trends. US GAO. October 2008. http://www.gao.gov/new.items/d0956.pdf. Accessed August 23, 2010.
28. Liability and Regulation of Autonomous Vehicle Technologies. Anderson, James; Kalra, Nidhi; Wachs, Martin. RAND. 2009. http://www.rand.org/pubs/external_publications/EP20090427/. Accessed August 23, 2010.
29. High-Tech Highways: ITS and Policy. Congressional Budget Office. October 1995. http://www.cbo.gov/doc.cfm?index=16&type=0. Accessed August 23, 2010
30. S. Rezaei and R. Sengupta "Kalman Filter-Based on Integration of DGPS and Vehicle Sensors for Localization," *IEEE Transactions on Control Systems Technology*, November 2007, Vol. 15, No. 6, pp. 1080-1088.
31. Chen, X., U. Vollath, H. Landau, K. Sauer. Will Galileo/Modernized GPS Obsolete Network RTK?. European GNSS 2004 Conference, May 16-19, 2004, Rotterdam, The Netherlands .
32. LeLievre, Jaqueline. GPSnet NRTK Corrections and Dynamic Accuracy Trials. GNSS Technical Support Newsletter. Issue 29, June 2008. pp. 6
33. Moahn, Brij and Jain, Pranay. A Seminar Report on GPS. The University of Rajasthan, Jaipur. http://www.scribd.com/doc/6698521/GPS-Final-Report. Accessed August 23, 2010

34. De Smith, Goodchild, and Longley. Geospatial Analysis, a Comprehensive Guide. 3rd Edition. http://www.spatialanalysisonline.com/output/html/InversedistanceweightingIDW.html. Accessed August 23, 2010.

Appendix A – Process of Selecting ITS Application that Stand to Benefit from C-HALO

Initial Application Selection Matrix (1,2)

ITS Applications	Safety	Location Services Necessary	Accuracy Requirements	Transmission	Min Frequency	Allowable Latency	Required Range
Units	(Y/N)	(Y/N)	(m)	(Event/Periodic)	(Hz)	(msec)	(m)
Traffic Signal Violation Warning*	Y	Y	1	P	10	100	250
Stop Sign Violation Warning	Y	Y	1	P	10	100	250
Curve Speed Warning*	Y	Y	1	P	1	1000	200
Emergency Electronic Brake Lights*	Y	Y	1	E	10	100	300
Adv. Warning Info/Weather & Road Conditions							
Approaching Emergency Vehicle Warning	Y	Y	5	E	1	1000	1000
Emergency Vehicle Signal Preemption	Y	Y	5	E	N/A	1000	1000
SOS Services	Y	Y	25	E	1	1000	400
Post-Crash Warning	Y	Y	1	E	1	500	300
In-Vehicle Signage	Y	Y	5	P	1	1000	200
Work Zone Warning	Y	N	N/A	P	1	1000	300
In-Vehicle Amber Alert	Y	N	N/A	E	1	1000	250
Safety Recall Notice	Y	N	N/A	E	N/A	5000	400
JIT Repair Notification	N	N	N/A	E	N/A	N/A	400

ITS Applications	Safety	Location Services Necessary	Accuracy Requirements	Transmission	Min Frequency	Allowable Latency	Required Range
Units	(Y/N)	(Y/N)	(m)	(Event/Periodic)	(Hz)	(msec)	(m)
Low Parking Structure Warning	Y	Y	5	P	1	1000	100
Wrong Way Driver Warning	Y	Y	1	P	10	100	500
Low Bridge Warning	Y	Y	5	P	1	1000	300
V2V Road Feature Notification	Y	Y	5	E	2	500	400
Cooperative Glare Reducation	N	Y	1	P	1	1000	400
Instant Messanging	N	N	N/A	E	N/A	1000	50
Vehicle-Based Road Condition Warning	Y	Y	25	E	2	500	400
Visibility Enhancer	Y	Y	1	P	2	100	300
Road Condition Warning	Y	N	N/A	E	1	1000	200
Highway Merge Applications							
Highway Merge Assistant	Y	N	N/A	P	10	100	250
Intelligent On-Ramp Metering	N	N	N/A	E	1	1000	100
Blind Merge Warning	Y	N	N/A	P	10	100	200
Left Turn Assistant*	Y	Y	1	P	10	100	300
Stop Sign Movement Assistance*	Y	Y	1	P	10	100	300
Pedestrian Crossing Information	Y	Y	1	P	10	100	200
Collision Warning Applications							
Pre-Crash Sensing*	Y	Y	1	E	50	20	50

ITS Applications	Safety	Location Services Necessary	Accuracy Requirements	Transmission	Min Frequency	Allowable Latency	Required Range
Units							
	(Y/N)	(Y/N)	(m)	(Event/Periodic)	(Hz)	(msec)	(m)
Cooperative Forward Collision Warning*	Y	Y	1	P	10	100	150
Cooperative Collision Warning	Y	Y	1	P	10	100	150
Highway/Rail Collision Warning	Y	Y	1	E/P	1	1000	300
Intersection Collision Warning	Y	Y	1	P	10	100	300
Adapative Headlight Aiming	Y	Y	1	P	1	1000	200
Adaptive Drivetrain Management	N	Y	5	P	1	1000	200
Lane Change Warning*	Y	Y	1	P	10	100	150
Blind Spot Warning	Y	Y	1	P	10	100	150
Corridor Management							
Cooperative Vehicle-Highway Automation System	Y	Y	5	P	50	20	100
Cooperative Adaptive Cruise Control	Y	Y	5	P	10	100	250
Intelligent Traffic Flow Control	N	Y	5	E	1	1000	250
Free-Flow Tolling	N	Y	1	E	N/A	50	50
Private Applications							
Enhanced Route Guidance & Navigation	N	Y	1	E	N/A	1000	200
Point of Interest Notification	N	Y	5	P	1	1000	400
Map Downloads & Updates	N	N	N/A	E/P	1	1000	400
GPS Correction	N	N	N/A	P	1	1000	400

Applications that stand to benefit from C-HALO

Safety

Curve Speed Warning
Aid drivers in negotiating curves at appropriate speeds.

Emergency Electronic Brake Light
Warns a driver when forward vehicle brakes hard (deceleration is above a predetermined threshold). This is very similar to Cooperative Forward Collision Warning which is used to preemptively avoid rear-end collisions with vehicles in front of the subject vehicle.

Highway Merge Assistant
Warns vehicles on highway on-ramps if another vehicle is occupying its merging space (or in its blind spot). This is similar to Blind Merge Warning where warnings are used for vehicles attempting to merge with limited sight distance, and another vehicles is predicted to occupy the merging space.

Blind Spot Warning
Warns subject driver if another vehicle is occupying his/her blind spot during an intended lane change maneuver.

Lane Change Warning
Warns subject driver if a lane change is likely to cause a collision. Triggered by turn signal activation.

Intersection Collision Warning
Provides warnings to drivers that a collision is likely at the upcoming intersection

Cooperative Collision Warning
Warns vehicles when a collision is likely with surrounding vehicles.

Left Turn Assistant
Provides drivers information about oncoming traffic when trying to take a left-hand turn at an unprotected intersection.

Stop Sign Movement Assistance
Warns vehicles about to cross an intersection, after stopping, of cross traffic.

Highway/Rail Collision Warning
Provides warnings to reduce the likelihood of a collision between vehicles and trains on intersecting paths.

Pedestrian Crossing Information
Alerts vehicles if there is danger of a collision with a pedestrian in a crosswalk.

Mobility

Free Flow Tolling
Toll collection without toll plazas reducing stop and go traffic surrounding current toll plazas.

Emissions

Adaptive Drivetrain Management
Allows vehicles to anticipate shift change patterns, and assist engine management systems to stabilize the transmission. Effects should be seen in increased gas mileage, reduced emissions, and improved shifting performance.

Mobility & Emissions

Intelligent On-ramp Metering
Uses real-time data to adjust ramp metering signal phases

Intelligent Traffic Flow Control
Use real-time data to adjust signal phases to an optimal level. Could also include Green Light Optimal Speed Advisory, which would provide the subject vehicle with the optimal speed given signal phase timing at upcoming intersections.

Private Applications (Etc.)
Enhanced Route Guidance & Navigation
Drive-thru Payments
Parking Lot Payment/Spot Locator

References
1. Lockheed Martin Federal Systems. ITS Performance and Benefits Study. June 1996.
2. The CAMP Vehicle Safety Communications Consortium. Identify Intelligent Vehicle Safety Applications Enabled by DSRC. March 2005.

Appendix B – Querying Methodology Matrix

	Driver Related Factors							Manner of Collision			Relation to Junction								Roadway Alignment		Traffic Control Device				Vehicle Manuever				
	Drowsy, Sleepy, Asleep, Fatigued	Operating in Careless or Inattentive Manner	Improper of Erratic Lane Changing	Failure to Keep in Proper Lane	Failure to Yield Right of Way	Driving Too Fast for Conditions	Driving in Excess of Posted Maximum	Front-to-Rear	All	Other	Intersection (Non-Interchange)	Intersection Related (Non-Interchange)	Rail Grade Crossing (Non-Interchange)	Crossover Related (Non-Interchange)	Intersection (Interchange Area)	Intersection Related (Interchange Area)	Crossover Related (Interchange Area)	All	Curve	All	Stop Sign	Stop Sign	Other	All	Turning Left	Changing Lanes or Merging	Negotiating a Curve	Other	All
Curve Speed Warning						X	X		X										X	X								X	X	
Electrtonic Brake Warning	X	X						X										X		X									X
Merge Warning (1)	X	X								X								X		X						X		X	
Merge Warning (2)			X	X						X								X		X						X		X	
Left Turn Assistant (1)					X					X	X	X		X	X	X	X			X					X			X	
Left Turn Assistant (2)	X	X								X	X	X		X	X	X	X			X					X			X	
Stop Sign Assistant	X	X								X	X	X		X	X	X	X			X	X	X						X	
Intersection Collision Warning	X	X								X	X	X		X	X	X	X			X			X					X	
Highway/Rail Collision Warning	X	X								X			X							X					X			X	

Appendix C – Efficacy Rate Matrix

	Low	Mid	High
Curve Speed Warning	20.00%	40.00%	70.00%
Emergency Electronic Brake Lights	10.00%	25.00%	50.00%
Highway/Rail Collision Warning	10.00%	25.00%	50.00%
Intersecton Collision Warning	25.00%	50.00%	75.00%
Left Turn Assistant	25.00%	50.00%	75.00%
Merge/Lane Change Applications	15.00%	35.00%	60.00%
Stop Sign Movement Assistance	25.00%	50.00%	75.00%
Free Flow Tolling		70.00%	
Intelligent Traffic Control		15.00%	